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Probabilistic inversion in the context of EM studies: Where we are and avenues for the future

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Modern Markov chain Monte Carlo (MCMC) algorithms can explore the posterior distribution of highly non-linear inverse problems in moderately high dimensions. For instance, 2-D magnetotelluric inversion is feasible for several hundreds of independent model parameters. At present, 3-D applications are limited to a few tenths of model parameters, but even such low dimensions make MCMC useful in time-lapse inversions when using appropriate model parameterizations. It is straightforward to invert for the noise level of the data (i.e. hierarchical Bayes) and the appropriate strength of the prior constraints (i.e. empirical Bayes). It is even possible to consider the dimension of the problem as an unknown (i.e. reversible-jump or transdimensional inversion). Nevertheless, persistent problems that plague MCMC inversions in geophysics include the choice of the prior probability density function, overly simplistic descriptions of data and modeling errors in the likelihood function, as well as truncation errors or spectral leakage that are inevitable when describing the Earth by a finite number of parameters. This leads to uncertainty estimates that often are overly optimistic (or alternatively limited by a too restrictive set of hypotheses) and final results that at times are only vaguely more informative than those obtained by classical Occam inversions. We argue that formal model selection, multiple-point statistics and approximate Bayesian computation may offer solutions to overcome some of these outstanding issues.